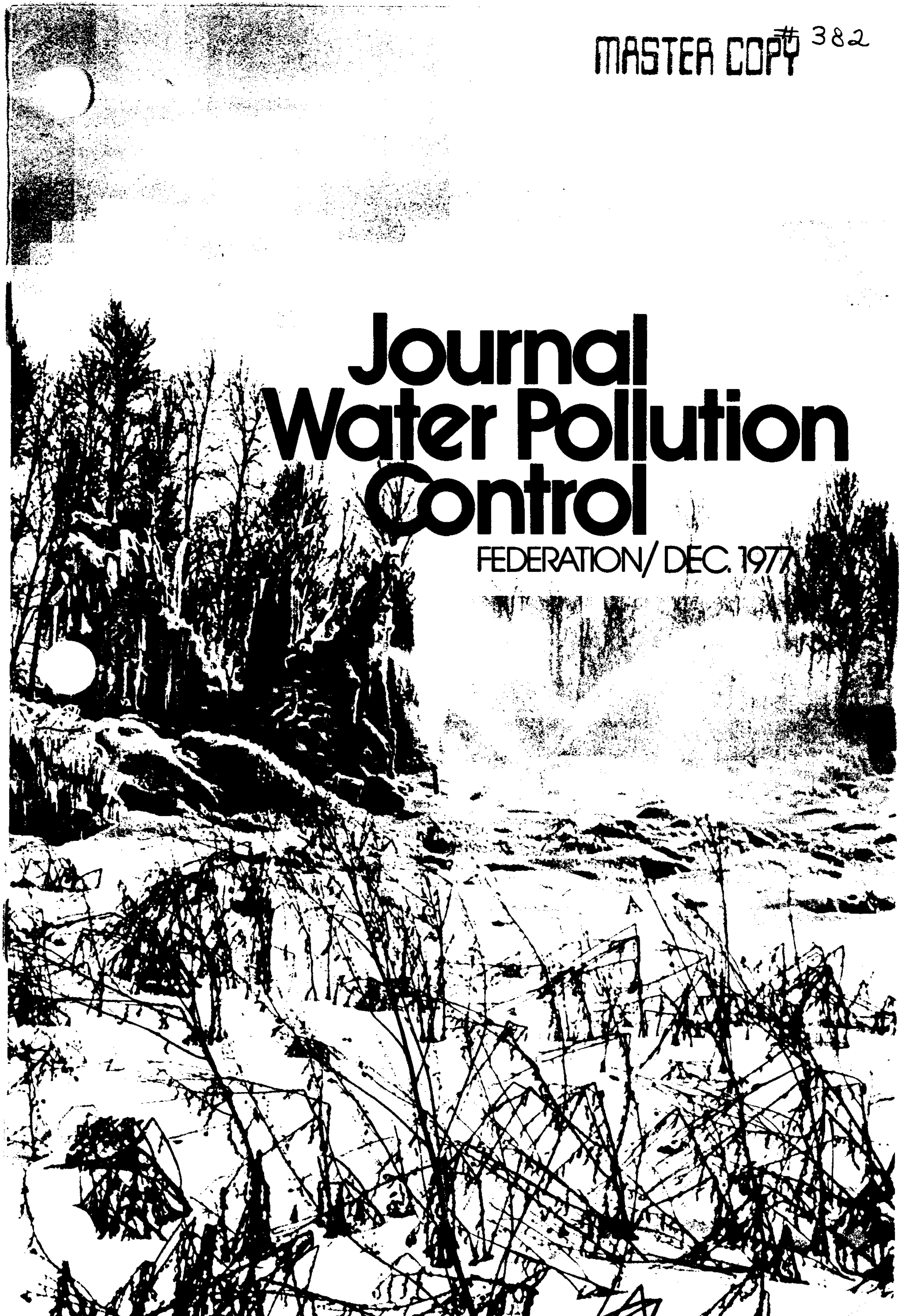

Journal Water Pollution Control

FEDERATION/ DEC. 1977

Microbial aerosols from food-processing waste spray fields

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Federal legislation restricts the discharge of waste from various industrial processes into rivers, lakes, or other waters. For this reason disposal of wastewater by spraying onto cultivated, grassed, or forested lands has come into use. These waste disposal spray systems produce droplets of water containing suspended material that may become aerosolized as particles less than about 20 μ in diameter. Particles of this size will remain suspended in the atmosphere and will travel long distances downwind. The generation of such particles by commercial spray or sprinkler equipment may be presumed because regardless of the size distribution for water droplets leaving the sprinkler nozzle a number of particles of aerosol size will develop through rapid evaporation. Solid materials, including microorganisms, suspended in the water become the nuclei of the aerosol particles. Recent reviews [1, 2] have been published regarding the aerosolization of microorganisms in sprays resulting from the treatment and disposal of wastewater from domestic waste. Microbial aerosol particles were sampled up to 1.2 km downwind of the spray source. Katzenelson and Teltch [3] reported aerosolized coliforms short distances downwind of spray fields for disposal of wastewater containing raw domestic waste and for disposal of effluent from a wastewater settling pond.

In this report, studies were made of microbial aerosols downwind from spray fields for the disposal of potato processing wastewater.

METHODS

Site. The test location was a processing waste spray field on the first bench level above a river. The field was bounded on the north and northeast by a second bench rising approximately 5 m above the first bench. On the west and southwest just beyond the edge of the field the land fell away to the river about 200 m beyond. The river bottom area was extensively tree-covered. Land in the other directions was open. The spray equipment was permanently installed and was equipped with rocker-arm type sprinklers having 7.1 and 2.4 mm nozzles discharging from risers 2 m high. The sprinklers were spaced on a grid at 30 by 33 m spacings. During Trials 1 and 2, four lines of eight sprinklers and one line of seven sprinklers per line were in operation, giving a source area of 150 by 320 m with the long axis east and west. Trials 3 through 5 had a source area of 150 by 270 m with 32 sprinklers operating, and Trials 6 through 9 had 27 sprinklers with a source area of 100 by 100 m. The pump flow rate and pressure were respectively 3.4×10^{-2} m^3/s and 4.5×10^5 N/m^2 (540 gpm and 65 psi) for Trials 1 through 7, and 3.8×10^{-2} m^3/s and 5.5×10^5 N/m^2 (600 gpm and 80 psi) for Trials 8 and 9.

Wastewater. Wastewater was derived from all processing activities in the plant and contained soil, potato, and plant fragments, potato peelings, rocks, suspended potato starch, and potato fluids. The rocks and large fragments were removed by sieve. The wastewater then entered a rectangular settling tank and then a sump from which it was pumped to the spray field. Composition of the wastewater was not determined for this study but has been published elsewhere.[4]

Meteorology. Two recording meteorological instruments were used, one stationed at the east side of the spray field on the first river bench, and the other north of the field on the

TABLE I. Meteorological and source input parameters for the area source diffusion model.

Meteorological Input Parameters

Atmospheric Stability	Parameters		
	σ_E' (radians)	σ_A' (radians)	H_m (meters)
Stable	0.0 524	0.0 524	30
Transitional	0.087 27	0.1 745	100
Unstable	0.1 745	0.3 491	1 000

Source Input Parameters

Trials	Parameters Values		
	y_o (meters)	x_o (meters)	σ_{zo} (meters)
1	320	150	3.54
2	320	150	3.54
3	270	150	3.54
4	270	150	3.54
5	270	150	3.54
6	100	100	3.54
7	100	100	3.54
8	100	100	3.54
9	100	100	3.54

second river bench. Sensors for the instruments to record wind speed, wind direction, and temperature were placed at 2 m above the ground level. Equipment to measure temperature gradient and wind direction and velocity to a suitable height was not available for use at the field location. However, estimates of meteorological parameters required for the area source diffusion model employed were based on measurements for similar wind and stability conditions measured at Dugway Proving Ground. The three atmospheric stability conditions used for grouping the field trials, as listed in Table I, are (1) stable, which is associated with a temperature inversion (that is, temperature increasing with height above ground level), which usually occurs during nighttime; (2) unstable, associated with lapse conditions (temperature decreasing with height) and usually occurring during daytime; and (3) transitional, representing that period when a shift from stable to unstable or vice versa is occurring, usually at dusk or at dawn. Steam discharge from the nearby processing plant provided an indicator of the stability condition at the time of each trial. Thus, steam rising sharply as it moved downwind indicated lapse while steam moving horizontally downwind indicated inversion.

Aerosol sampling. Sampling was conducted in late September. A trial consisted of continuous sampling with aerosol samplers[5] for a designated interval ranging from 5 to 60 minutes depending on sampler locations. Samplers were located at three sampling stations downwind of the spray field. Sampling Station 1 was 15 m downwind of the downwind edge of the spray field, Station 2 varied from 91 to 396 m downwind, and Stations 3, 1 005 to 1 493 m downwind. Downwind distance for Stations 2 and 3 depended on accessibility of sampling sites with different wind directions. Two samplers, one containing plates of casitone agar and one containing plates of Endo's agar, were placed at Station 1 and at Station 2. One sampler containing plates of Endo's agar and three containing casitone agar were placed at Station 3. The three samplers of casitone plates at Station 3 were spaced approximately 320 m along a crosswind line.

Area source model. The ground-level concentration at a distance x from the downwind edge of an area source is given by the expression

$$\chi\{x > x_o, y\} = \frac{Q}{\sqrt{2\pi}\bar{u}\sigma_z\{x\}y_o} \times \{\text{Vertical Term}\} \times \{\text{Lateral Term}\} \times \{\text{Decay Term}\} \quad (1)$$

where

x_o = along wind dimension of the area source
y = crosswind distance from the centerline of the area source
Q = area source strength in units of mass per unit time
$\bar{u}$ = mean wind speed
y_o = crosswind dimension

$$\sigma_z\{x\} = \begin{cases} \dfrac{\sigma_E' x_o}{\ln\left[\dfrac{\sigma_E'(x + x_o) + \sigma_{zo}}{\sigma_E'(x) + \sigma_{zo}}\right]}; x < 3x_o \\ \sigma_E'(x + x_o/2) + \sigma_{zo}; x \geq 3x_o \end{cases} \quad (2)$$

where

σ_{zo} = vertical source dimension
σ_E' = standard deviation of the wind elevation angle in radians

The Vertical Term is given by

Vertical Term

$$= \left\{1 + 2 \sum_{n=1}^{\infty} \left\{\exp\left[-\tfrac{1}{2}\left(\frac{2nH_m}{\sigma_z\{x\}}\right)^2\right]\right\}\right\} \quad (3)$$

where

H_m = depth of the surface mixing layer

The Lateral Term is given by the expression

Lateral Term

$$= \left\{\mathrm{erf}\left[\frac{y_o/2 + y}{\sqrt{2}\sigma_y\{x\}}\right] + \mathrm{erf}\left[\frac{y_o/2 - y}{\sqrt{2}\sigma_y\{x\}}\right]\right\} \quad (4)$$

where

$$\sigma_y\{x\} = \sigma_A'(x + x_o/2) \quad (5)$$

σ_A' = standard deviation of the azimuth wind angle in radians

The Decay Term is given by

$$\text{Decay Term} = \exp(-k\bar{t}) \quad (6)$$

where

k = decay coefficient or fraction of material lost per unit time
$\bar{t}$ = mean cloud travel time $\cong x/\bar{u}$

In this note, decay is not considered and the Decay Term is therefore set equal to unity. Also, only centerline concentrations ($y = 0$ in Equation 4) have been calculated.

Meteorological and source parameters used are shown in Table I. The values of σ_A' and σ_E', based on measurements made at Dugway Proving Ground for wind and apparent stability conditions similar to those at the test site, are applicable for averaging times of the order of 10 minutes. Values of H_m are also based on the Dugway measurements.

The location of the samplers was always such that the largest source dimension of the source area represented Y_o and the smallest dimension represented x_o. The vertical source dimension σ_{zo} was estimated from the relationship

$$\sigma_{zo} = \frac{h}{2.15} \quad (7)$$

where h is the estimated height of the water spray cloud at the source, or 7.62 m.

RESULTS

Samples of wastewater taken at the inflow and at the outflow of the settling tank and from the sump tank had total microbiological counts (counts on casitone agar) of 1.00×10^6, 2.20×10^9, and 2.25×10^9 organisms per ml respectively. Corresponding coliform counts (on Endo's agar) were 8.85×10^5, 1.18×10^6, and 1.61×10^6, respectively. Since the inflow total count was only 12 percent greater than the coliform count, the bulk of the organisms at the settling tank inflow were assumed to be coliforms. At the outflow, the coliform count had increased only 33 percent, showing relatively slight growth of coliforms in the settling tank. In comparison, the total count had increased by a factor of 2 200, indicating an impressive increase in non-coliforms in the wastewater as it passed through the settling tank. A limited effort was made to characterize the organisms associated with aerosol particles generated at the spray field. Pink colonies growing on Endo's agar were counted as coliforms and colonies that developed a metallic sheen on Endo's agar were assumed to be *Eschericia coli.* No further confirmation was attempted. The colony counts indicated that less than 10 percent of the coliforms were *E. coli.* Three colony types were predominant on the casitone agar, all of which were capable of hydrolyzing starch. The most common colony was found to be a starch-hydrolyzing streptococcus, possibly *Streptococcus bovis.*

Usable data were obtained for nine trials. Six trials were not successful because of wind cessation, sampler failure, or other causes. The conditions for each of the successful trials are given in Table II. The observations in the right-hand column were used to estimate atmospheric stability conditions for each trial.

TABLE II. Time and field conditions for sampling trials.

Trial Number	Time of Trial (MDT)	Time of Sunrise or Sunset (MDT)	Mean Wind Speed (m/s)	Field Observations
1	0720–0820	0725	1.8	Steam from nearby plant slightly rising
2	0900–1000	0725	2.0	Steam not rising at start of trial; rising after 0915
3	0615–0700	0740	1.0	Steam at plant not rising; pre-dawn inversion
4	0745–0830	0740	1.3	Steam rising slightly at 0831 and rising sharply at 0843
5	1800–1915	1930	2.3	Dust layer near surface; inversion
6	0610–0630	0725	0.8	Steam from plant not rising; inversion
7	0635–0700	0725	0.8	Steam from plant not rising; inversion
8	0900–0930	0725	1.8	Bright sun; lapse
9	0930–1000	0725	1.8..	Bright sun; lapse

Based on these conditions, the trials were grouped into three general stability categories (Table III). Also given for each of the trials is the downwind distance from the source field to the sampling station, the concentration of the total microbial particles at the sampling station, and the normalized concentration obtained by dividing the concentration at each of the sampling stations by the concentration at the first sampling station. The first stage of the sampler collects particles that are mos larger than 20 μ in diameter and have appreciable settling velocity. These were cluded in calculating downwind concentration because their downwind travel is not great and is not accounted for by the diffusion model.

TABLE III. Concentrations of total bacteria bearing particles at downwind stations for trials in three atmospheric stability categories.*

	Sampling Station 1			Sampling Station 2			Sampling Station 3		
Trial No.	Downwind Distance (m)	Concentration (Particles/m³ × 10³)	Normalized Conc.	Downwind Distance (m)	Concentration (Particles/m³ × 10³)	Normalized Conc.	Downwind Distance (m)	Concentration (Particles/m³ × 10²)	Normalized Conc.
				Stable					
3	15	6.76	1	396	2.91	0.430	1 493	8.30	0.123
5	15	6.72	1	91	5.38	0.800	1 310	4.13	0.061
6	15	6.56	1	122	3.83	0.583	1 005	8.76	0.133
7	15	8.56	1	122	3.92	0.458	1 005	19.70	0.230
				Transitional					
1	15	4.50	1	305	0.64	0.142	1 372	3.00	0.067
4	15	24.80	1	396	3.41	0.137	1 493	5.22	0.021
				Unstable					
2	15	4.88	1	305	0.46	0.094	1 372	0	0
8	15	30.80	1	122	4.20	0.136	1 005	0.53	0.002
9	15	19.10	1	122	4.25	0.222	1 005	0.11	0.001

* Concentration excludes particles on first stage of sampler.

TABLE IV. Coliform-bearing particle concentrations at downwind stations for trials in three stability categories.*

	Sampling Station					
	1		2		3	
Trial No.	Concentration (Particles/m³)	Normalized Conc.	Concentration (Particles/m³)	Normalized Conc.	Concentration (Particles/m³)	Normalized Conc.
			Stable			
3	777	1	182.0	0.234	9.78	0.012
5	431	1	74.7	0.173	0.00	
6	615	1	366.0	0.595	25.30	0.041
			Transitional			
1	408	1	91.2	0.224	27.40	0.067
4	1 130	1	292.0	0.262	32.00	0.029
			Unstable			
8	816	1	207.0	0.254	4.13	0.005

* Concentration excludes particles on the first stage of the sampler.

Coliform-bearing particle concentrations and associated normalized concentrations for trials in the three stability categories are presented (Table IV) for those trials for which coliform counts were obtained.

The three atmospheric stability categories into which the trials were separated were based on time of day and upon field observation. Trials conducted before sunrise were placed in the stable category, as well as Trial 5, conducted just before sunset. Trials placed in the unstable category were conducted during daylight hours under what appeared by field observation to be atmospheric lapse, and trials in the transitional category were conducted after sunrise during the warming transition from night to day.

Using the parameters presented in Table I for the three stability categories, predicted normalized downwind concentration distributions were derived from the area source diffusion model and are plotted in Figures 1, 2, and 3 for stable, transitional, and unstable categories, respectively. Also, the normalized measured particle concentration distributions are plotted in these figures. The normalization eliminated trial-to-trial variation for both source strength and wind speed from the concentration data. Because of field conditions encountered, all of the trials were conducted during low wind speeds. Measured concentration distributions for stable conditions are in good agreement with the predicted distribution. Also, for transitional and unstable categories, the agreement between predicted and measured distributions is reasonably good, considering the small number of trials and the assumptions made in estimating the model inputs. In all stability categories, there is a tendency for the downwind measured concentrations to decline somewhat more rapidly than predicted. This is particularly true for the unstable category.

DISCUSSION

The results of this study have established that aerosol particles bearing microorganisms are produced when food processing wastes are sprayed on a disposal field. The area source diffusion model used here fairly accurately predicted the measured downwind concentrations. It is evident that, at least during the summer months, aerosol cloud travel during daylight would not be extensive because of rapid dispersion of the cloud in the unstable atmosphere. Though it could not be confirmed, it is likely that microbial decay would be appreciable during daylight hours through exposure of the organisms to ultraviolet radiation.

The ratio of total bacteria-bearing particles to coliform-bearing particles calculated from the counts presented in Tables III and IV was not comparable to the ratio of total count to

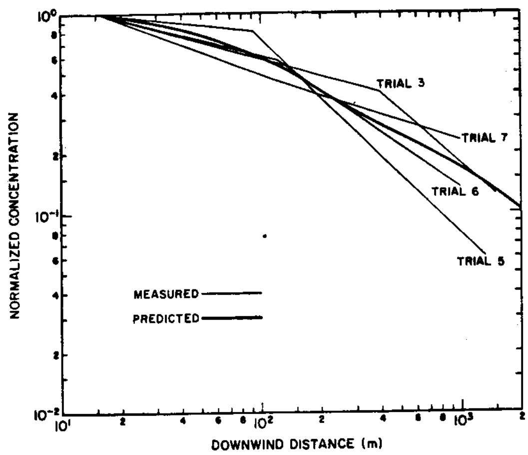

FIGURE 1. Measured and predicted concentrations downwind from the area sources for stable meteorological conditions.

coliform count for the wastewater at the sump tank. This resulted because a colony that develops on an Andersen sampler plate originates from an aerosol particle or particles that may contain many organisms but as few as one coliform. Thus, the count is a count of particles rather than a cell count. Thus, the percentage of total particles that are coliform-bearing can be much higher than the percentage of total organisms that are coliforms.

The trial-to-trial comparisons of the normalized values for total microbial particle concentrations and coliform particle concentrations

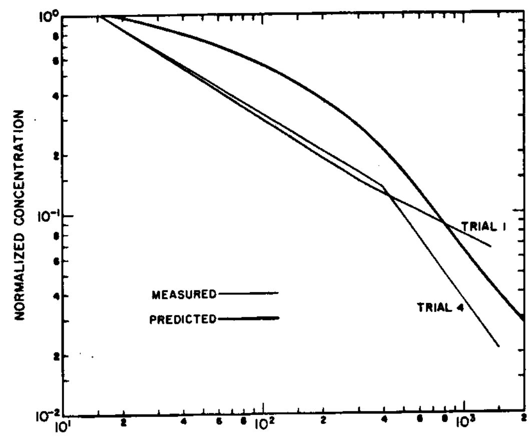

FIGURE 2. Measured and predicted concentrations downwind from the area sources for transitional meteorological conditions.

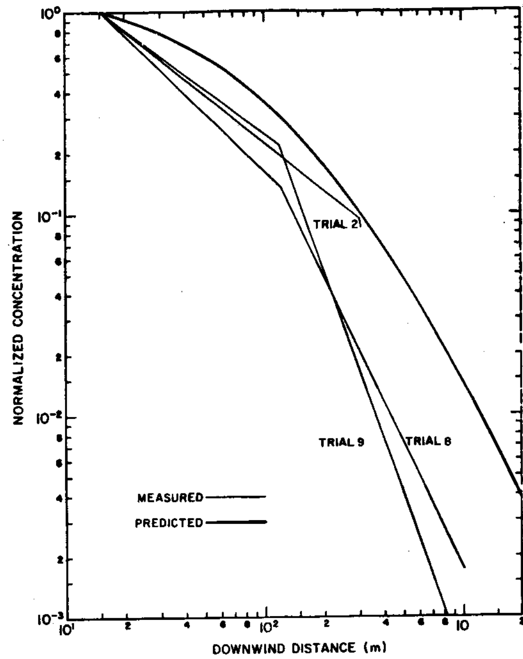

FIGURE 3. Measured and predicted concentrations downwind from the area sources for unstable meteorological conditions.

show considerable variability. However, considering the limited number of samples involved and the variability inherent in the sampling procedures attributable to cloud heterogeneity, wind variation, differences in duration of sampling, possibilities of extraneous contamination, and the general variability of biological assay, it must be concluded that the values represent relatively good agreement.

During summer, in the area studied, wind at night is slight to nonexistent. However, when wind did develop during periods of atmospheric stability as occur at night, the aerosol particles travelled downwind.

Using the predicted concentration distribution for stable conditions shown in Figure 1 and setting the concentration at Station 1 equivalent to that for Trial 3 (Table III), an estimated downwind concentration of 127 particles/m^3 at approximately 10 km is obtained. This concentration at this downwind distance reaches a dilution level that is indistinguishable from background or control concentration. The concentration at Station 1 for Trial 3 is typical for most of the trials. However, if the source is increased, as was apparent from the concentration at Station 1 in Trial 4 (with the same area source as Trial 3), then the downwind distance at which the concentrations would become non-detectable for stable conditions would be between 25 and 30 km. For the transitional conditions that actually existed for Trial 4, the concentration would become non-detectable at approximately 5 km. If wind speeds were greater than the low ones encountered, the downwind concentration would decrease because of greater turbulent mixing and mixing in greater volume of air. The downwind concentration distribution for aerosol particles bearing coliform bacteria would be similar to that discussed above for total organisms, except that it would approach or perhaps exceed 10-fold less than total concentration. The downwind concentration of coliform-bearing particles was comparable to that found downwind of wastewater trickling filter beds.[6]

As stated above, the measured concentrations tended to drop below the predicted level at the third sampling station. This was particularly noticeable for the trials in unstable meteorological conditions. There are three possible explanations for this drop:

1. Errors may exist in the estimates of model inputs which would result in an underestimation of vertical cloud growth, particularly in unstable conditions.
2. In the model calculations, decay, or loss of viability of the microorganisms with downwind travel, was not considered to occur because no means were available for assessing it. However, some decay undoubtedly occurred, particularly during daylight. Decay would contribute to a lower than predicted concentration at the farther downwind sampling stations.
3. Of the three samplers for total count that were on a crosswind line at the third sampling station, only the one with the highest concentration of particles was used as the one most likely to have been near the crosswind center of the cloud. In reality, the sampler may have been out of the cloud for brief periods with intermittent shifts in wind direction.

ACKNOWLEDGMENTS

Credits. Appreciation is extended to Bruce Grim, Dugway Proving Ground, Dugway, Utah, and to Keith Dumbauld, H. E. Cramer Co., Salt Lake City, Utah, for assistance with evaluation of the meteorological data and use of the area source diffusion model developed by H. E. Cramer Co. This paper was supported by DA Project 1T061101A91, In-House Laboratory Independent Research, U. S. Army Dugway Proving Ground, and by the Western Region, Agricultural Research Service, USDA, Kimberly, Idaho. This paper was presented at the 42nd Annual Meeting of the Pacific Northwest Pollution Control Association, Boise, Idaho, October 22–24, 1975.

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